Evaluation of mountain drag schemes from regional simulation

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Strategies for evaluating and tuning drag schemes

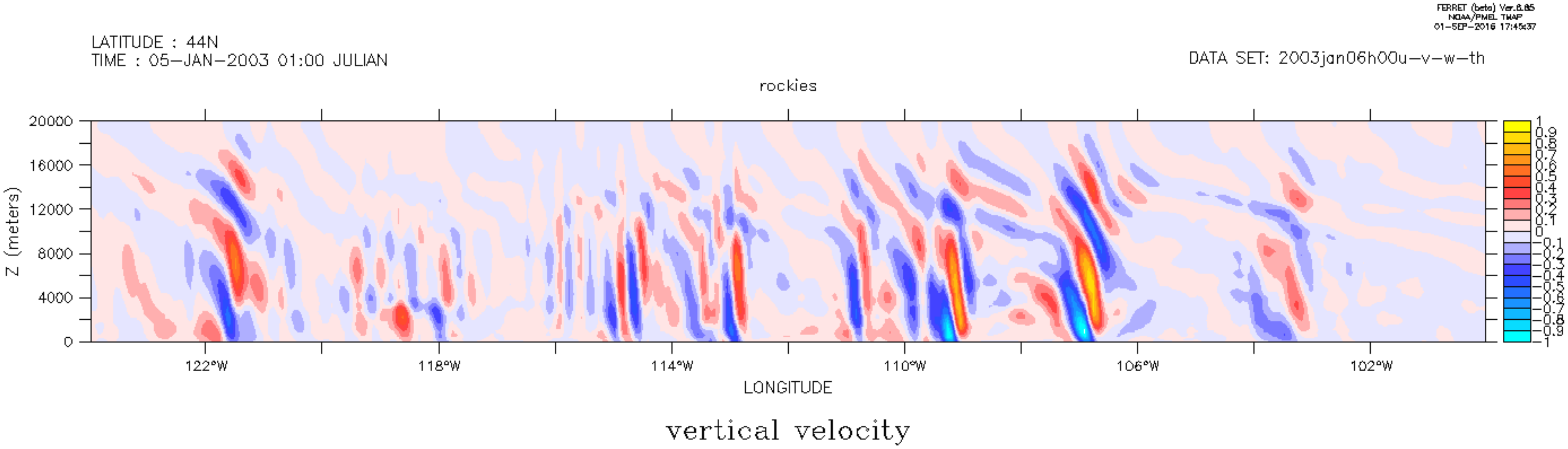
1. Optimize climate diagnostics (e.g., Palmer et al. 1986)
2. Correct biases in forecast mode (e.g., Klinker & Sardeshmukh 1992)
3. Match regional observations
4. Match ground-truth simulations

Ground-truth regional model:

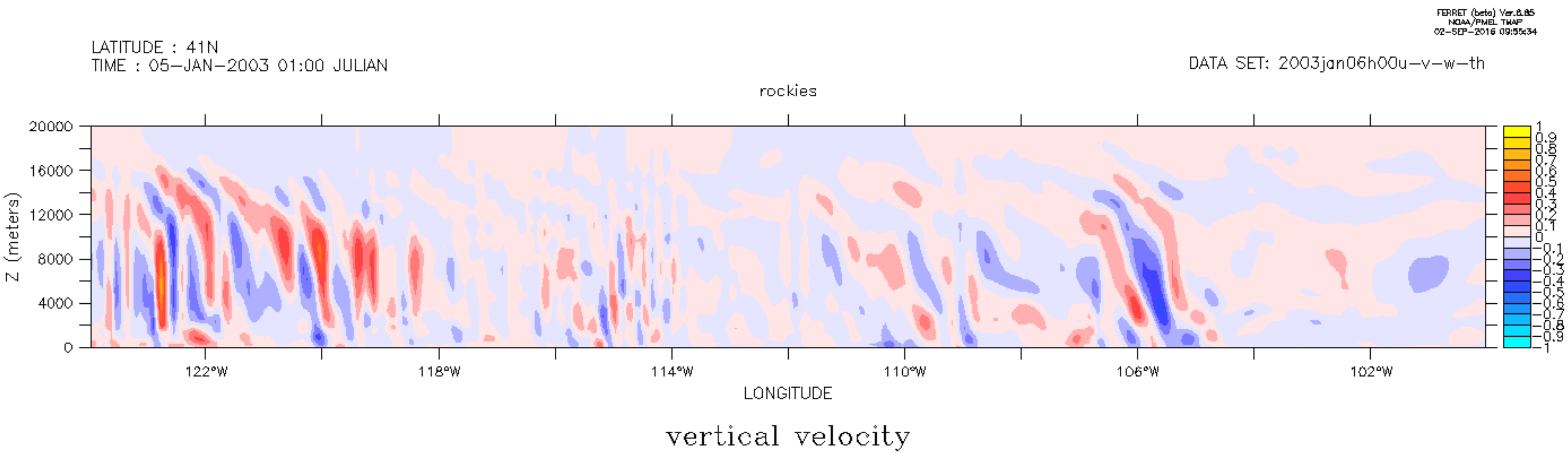
- compressible, non-hydrostatic
- terrain-following coordinate
- comprehensive physics
- nudging near lateral boundaries
- 5km horiz, 100-200m vertical

Driving:

- Idealized jet
- January reanalysis

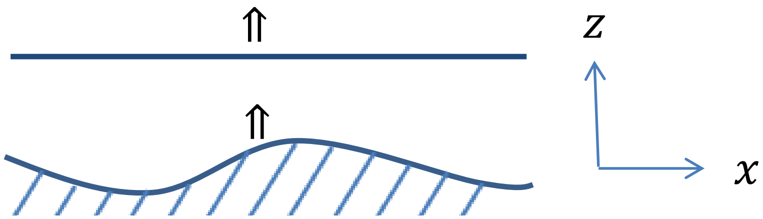


Driving: Idealized westerly jet



Driving: January reanalysis

Given a high-res simulation as ground truth, what is the resolved quantity that corresponds to the parameterized base flux?



Equation of motion:

$$\frac{\partial u}{\partial t} = -\vec{V}\cdot\nabla u - \frac{1}{\rho}\frac{\partial p}{\partial x} = -\nabla\cdot\left(\vec{V}u + \hat{\imath}\,\frac{p}{\rho_0}\right)$$

Momentum budget:

$$\frac{d}{dt}\iiint u\,dV \;=\; \oiint dA\left(V_n u + i_n\frac{p}{\rho_0}\right)$$

$$= \iint_{Top-Bot} dA\{uw - uv\frac{\partial h}{\partial y} - \left(u^2 + \frac{p}{\rho_0}\right)\frac{\partial h}{\partial x}\}$$

Momentum Flux: $$F_x{}^{\uparrow} = uw - uv\frac{\partial h}{\partial y} - \left(u^2 + \frac{p}{\rho_0}\right)\partial h/\partial x$$

Bernoulli: $$\frac{p}{\rho_0} = \phi_0 - \frac{|\vec{u}|^2}{2}$$

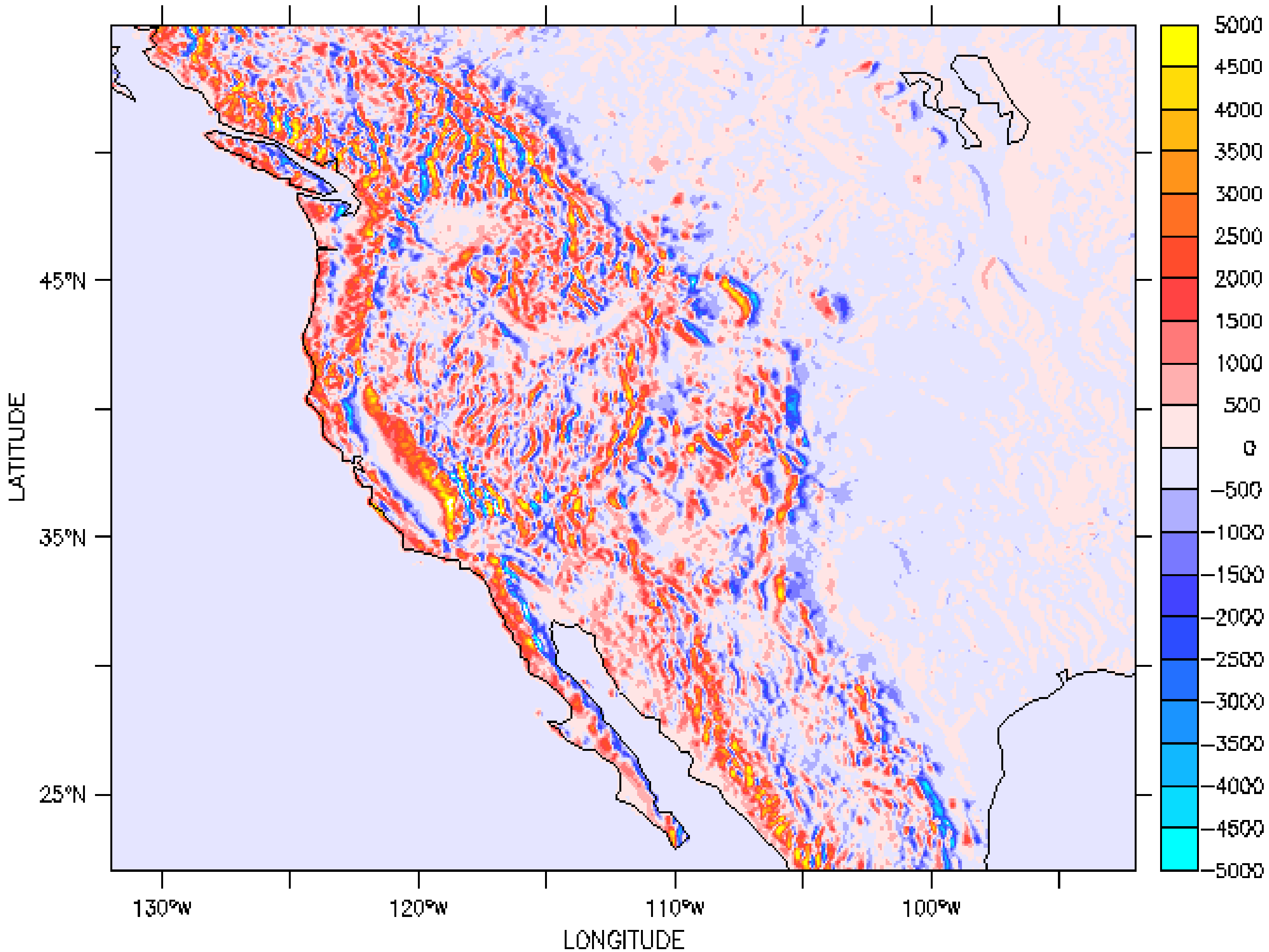
Then, locally at a solid boundary, $z = h(x, y)$,

$$F_x{}^{\uparrow} = \frac{|\vec{u}|^2 - |\vec{u}_{LS}|^2}{2}\partial h/\partial x \;\; + \;\; \text{dipoles}$$

where $\vec{u}_{LS}$ is a “large-scale” flow that doesn’t rectify.

How best to define “large-scale?”

Simulated form drag : $p\partial h/\partial x$

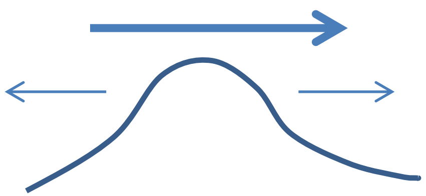


zonal form drag

To define the large-scale, try the partition , $\vec{u} = \vec{u}_{div} + \vec{u}_{nondiv}$,

and assume (as in the linear limit) that

$$\vec{u}_{LS} \approx \vec{u}_{nondiv} \quad \text{and} \quad \vec{u}_{gwd} \approx \vec{u}_{div}$$



Then $$F_x^{\uparrow} = \frac{|\vec{u}|^2 - |\vec{u}_{LS}|^2}{2} \partial h/\partial x$$

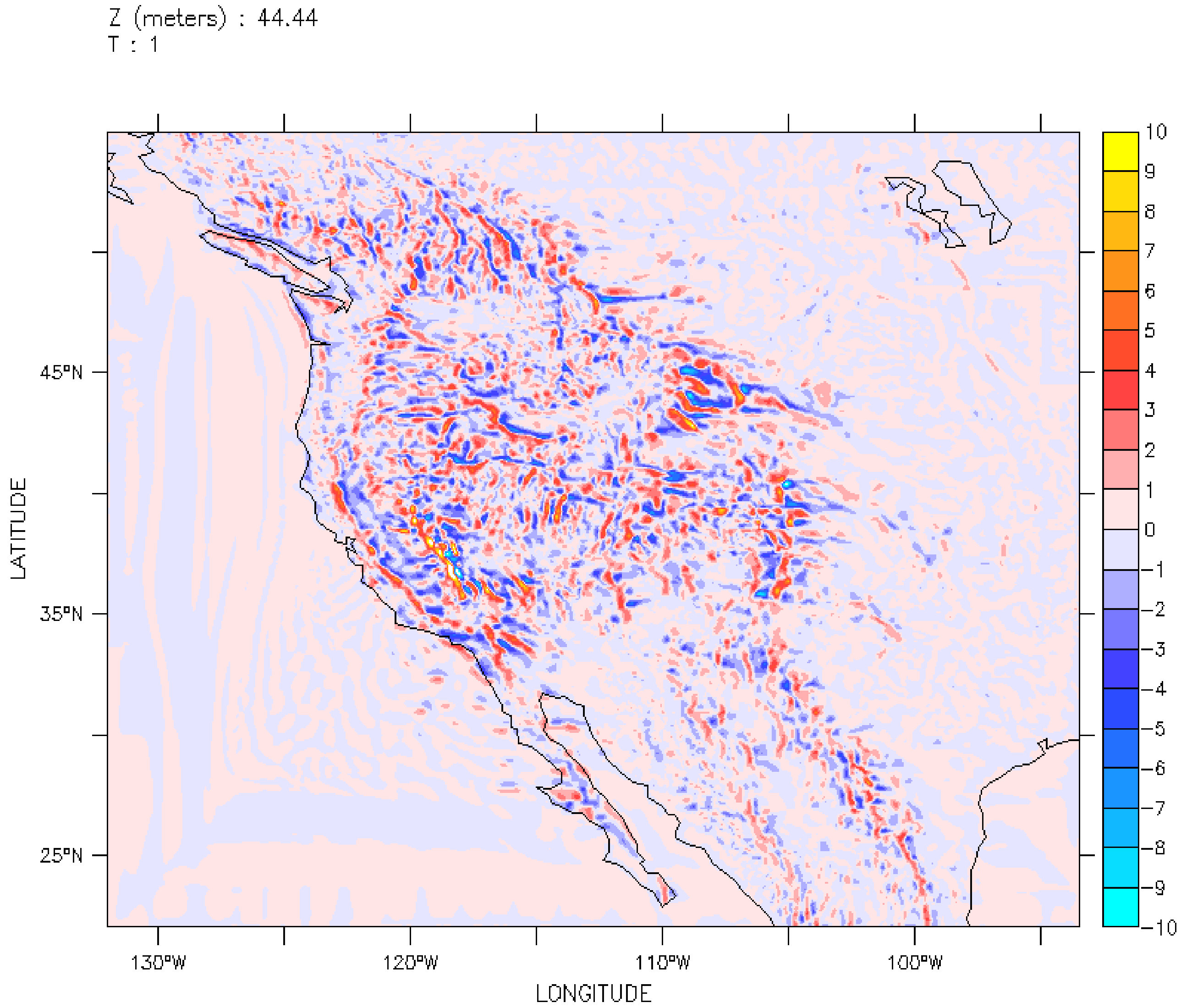
$$= \frac{\left|\vec{u}_{gwd}\right|^2}{2} \partial h/\partial x + v_{LS}\, \vec{u}_{gwd} \cdot \nabla_{\perp} h + u_{gwd} w_{LS}$$

$$F_y^{\uparrow} = \frac{|\vec{u}|^2 - |\vec{u}_{LS}|^2}{2} \partial h/\partial y$$

$$= \frac{\left|\vec{u}_{gwd}\right|^2}{2} \partial h/\partial y - u_{LS}\, \vec{u}_{gwd} \cdot \nabla_{\perp} h + v_{gwd} w_{LS}$$

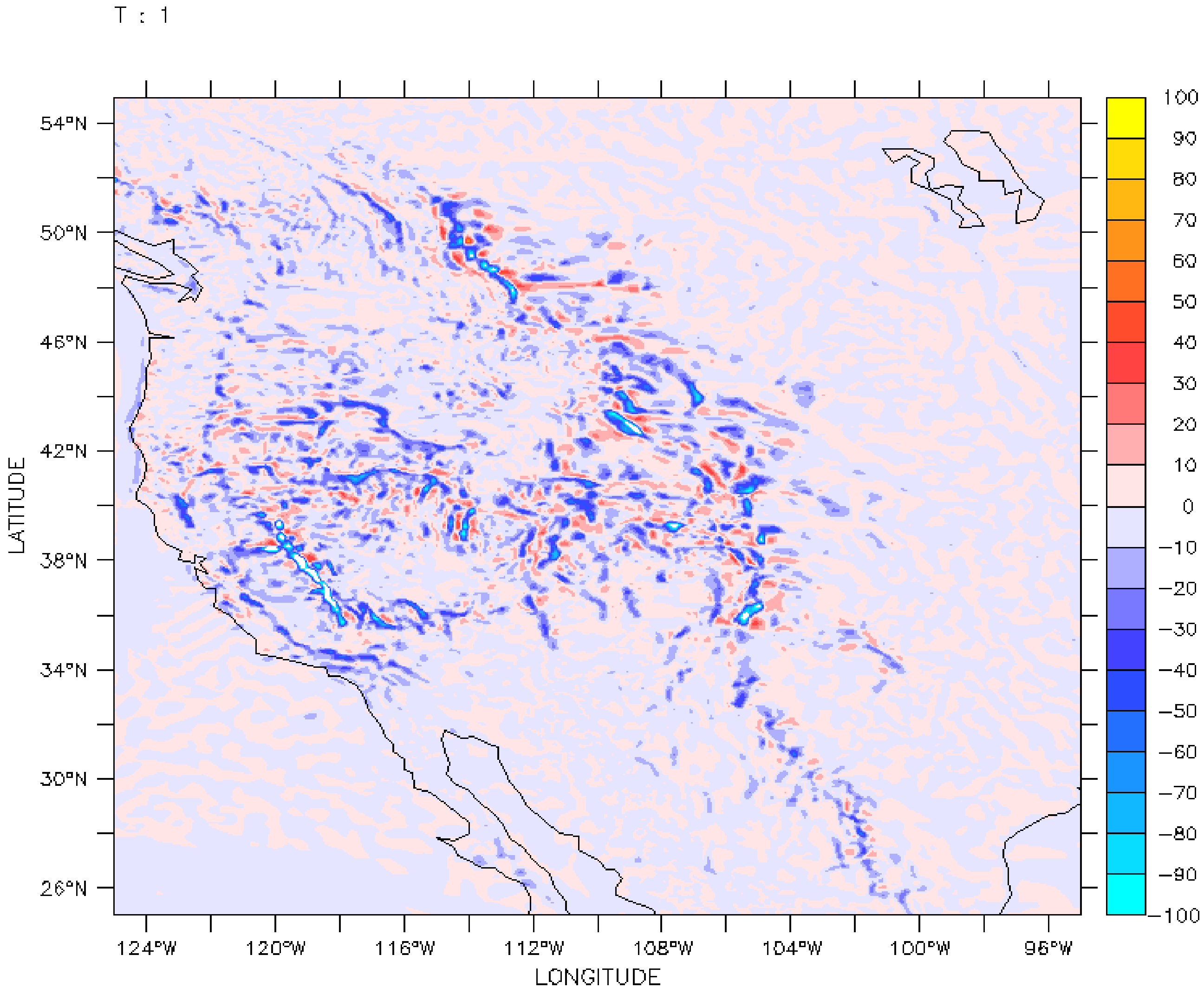
where $w_{LS} = \vec{u}_{LS} \cdot \nabla h$

Divergent velocity at $z_{agl} = 44$ m



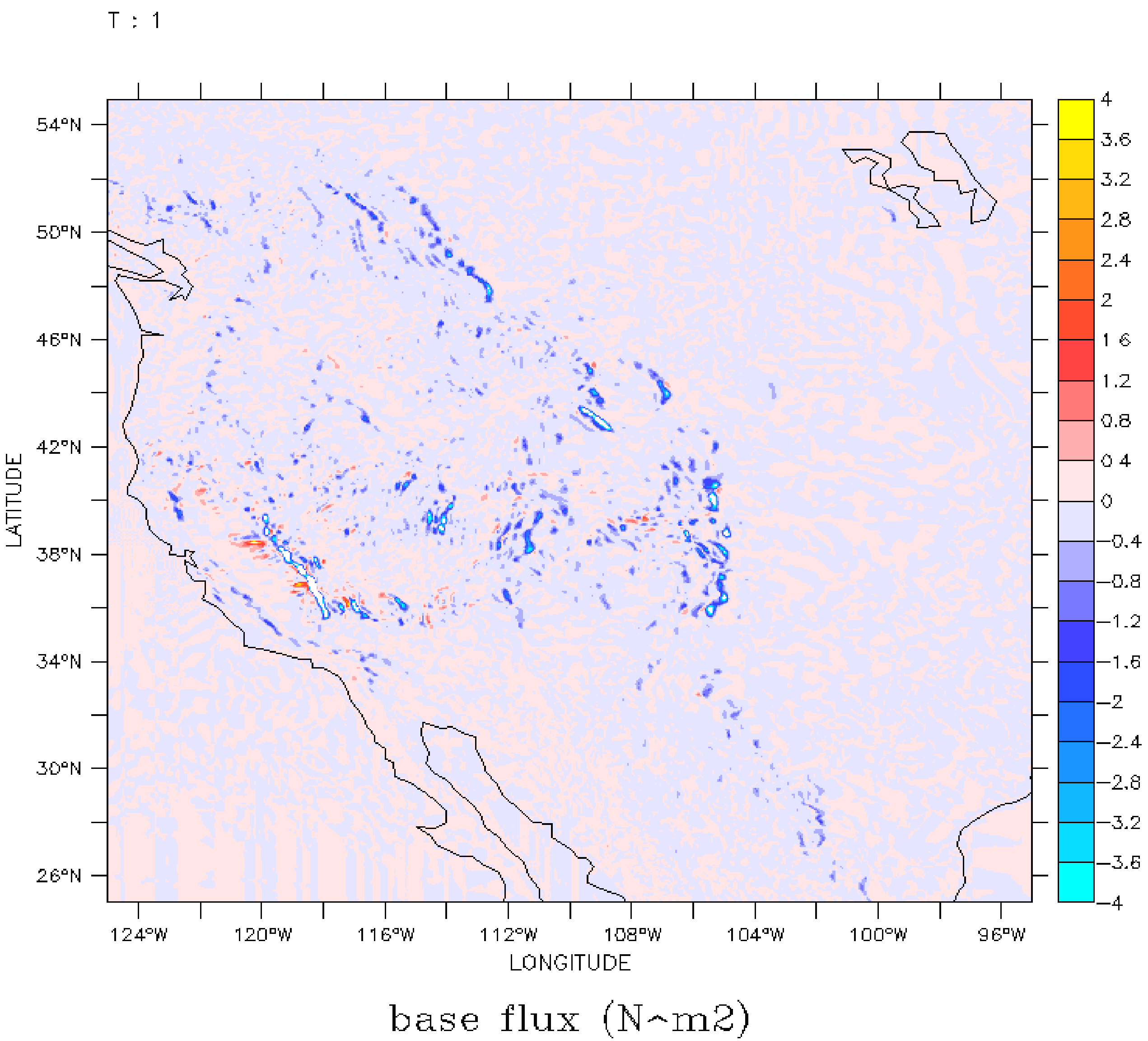
x−component of divergent velocity (m/s)

“Local” pressure at $z_{agl} = 44$ m

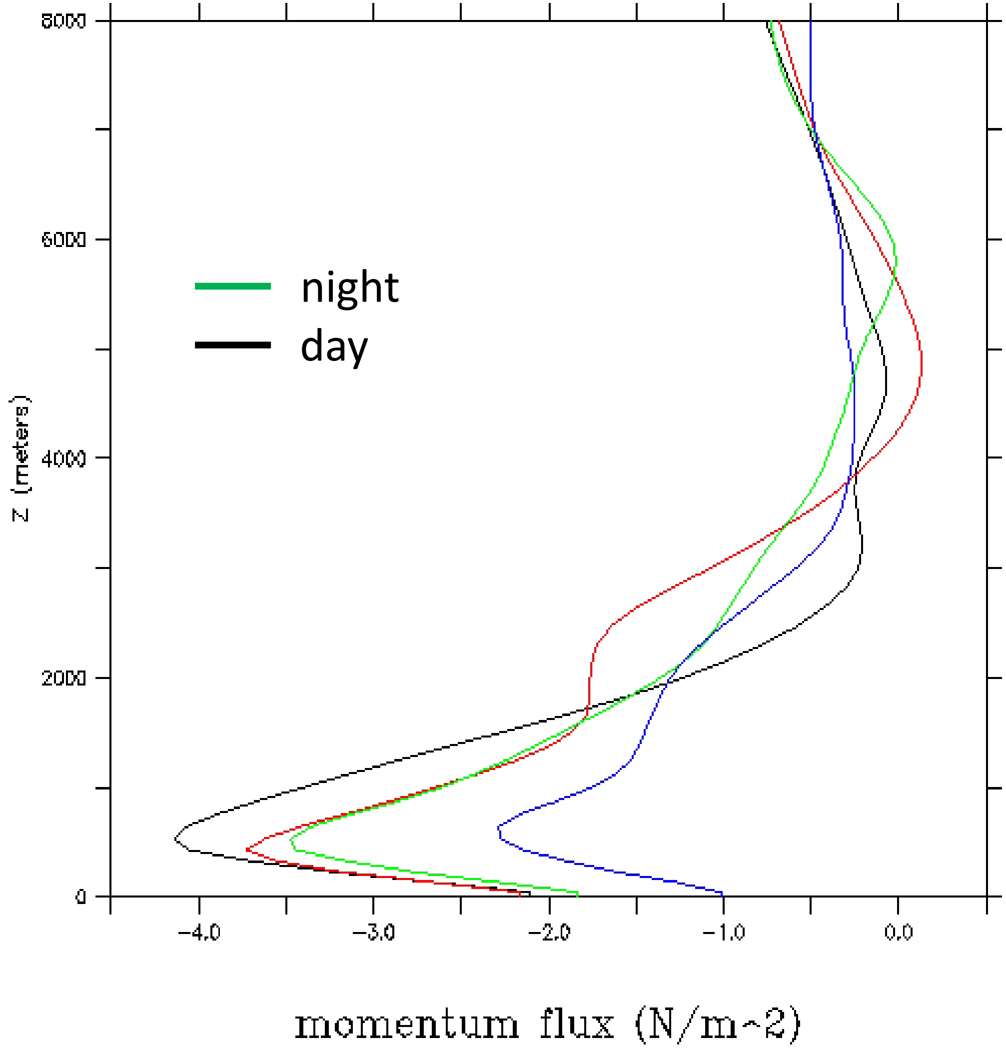


local pressure (Pa)

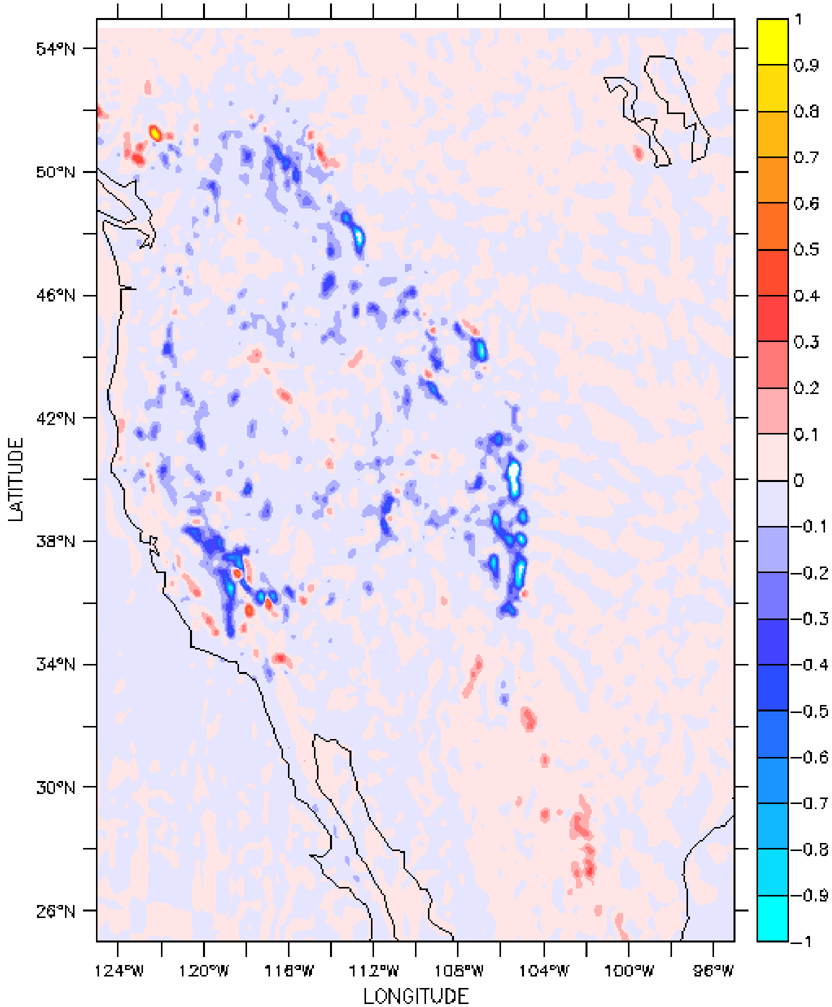
momentum flux at top of PBL



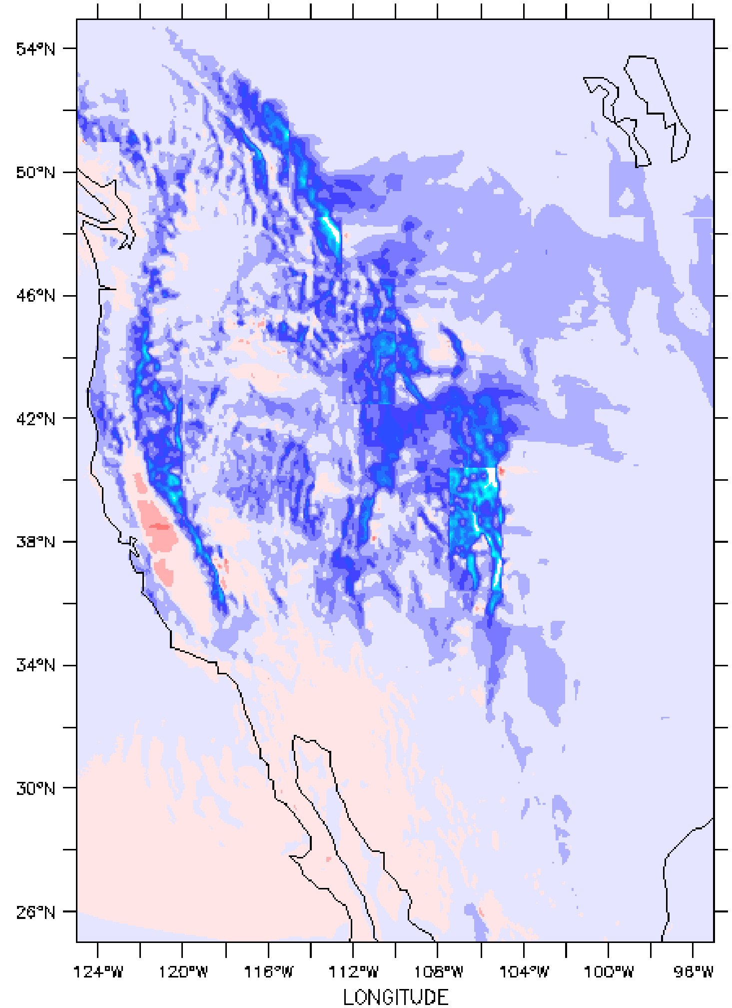
Zonal Momentum Flux
105° W, 40°N



main terms in PBL momentum budget

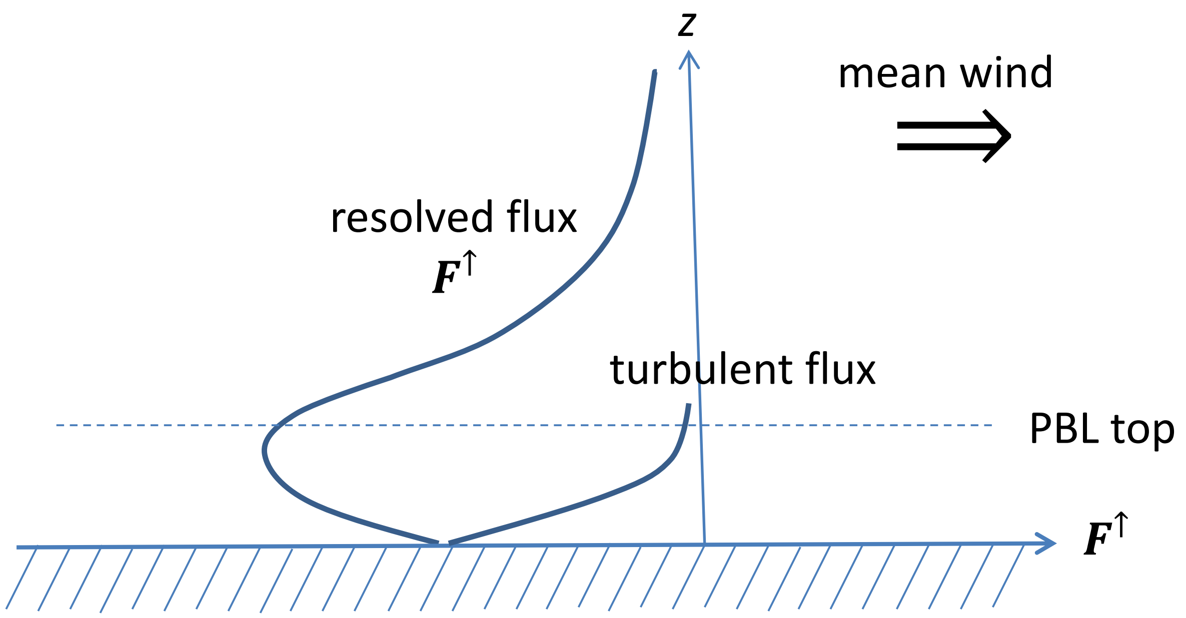


resolved momentum flux (N/m^2)



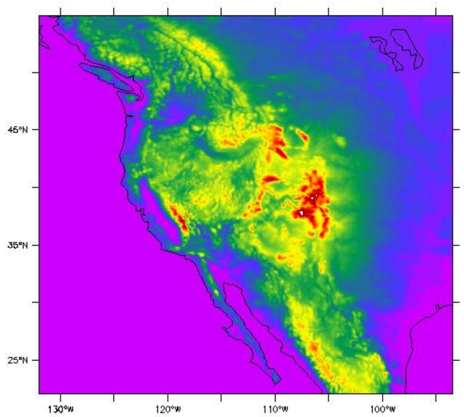
turbulent momentum flux (N/m^2)

Boundary layer balance, simplified



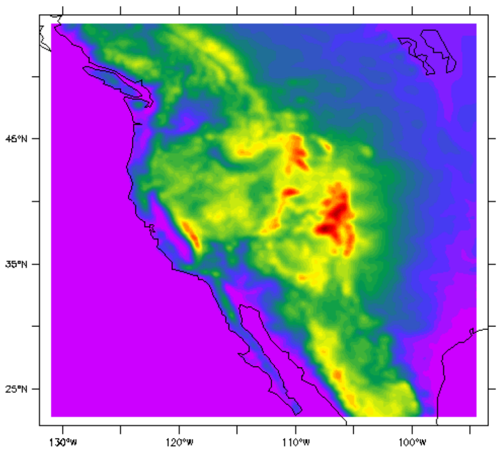
Evaluation Strategy

A: Fine



1 Run the high-res model
2 Diagnose the drag
3 Coarsen to match “B” gridsize

B: Coarse



1 Coarsen the “A” solution
2 Parameterize the drag
3 ← Compare

Optimization: For a base-flux scheme of the form

$$\boldsymbol{F}^{\uparrow} = a\boldsymbol{F}_{lin}{}^{\uparrow} + b\boldsymbol{F}_{nl}{}^{\uparrow} ,$$

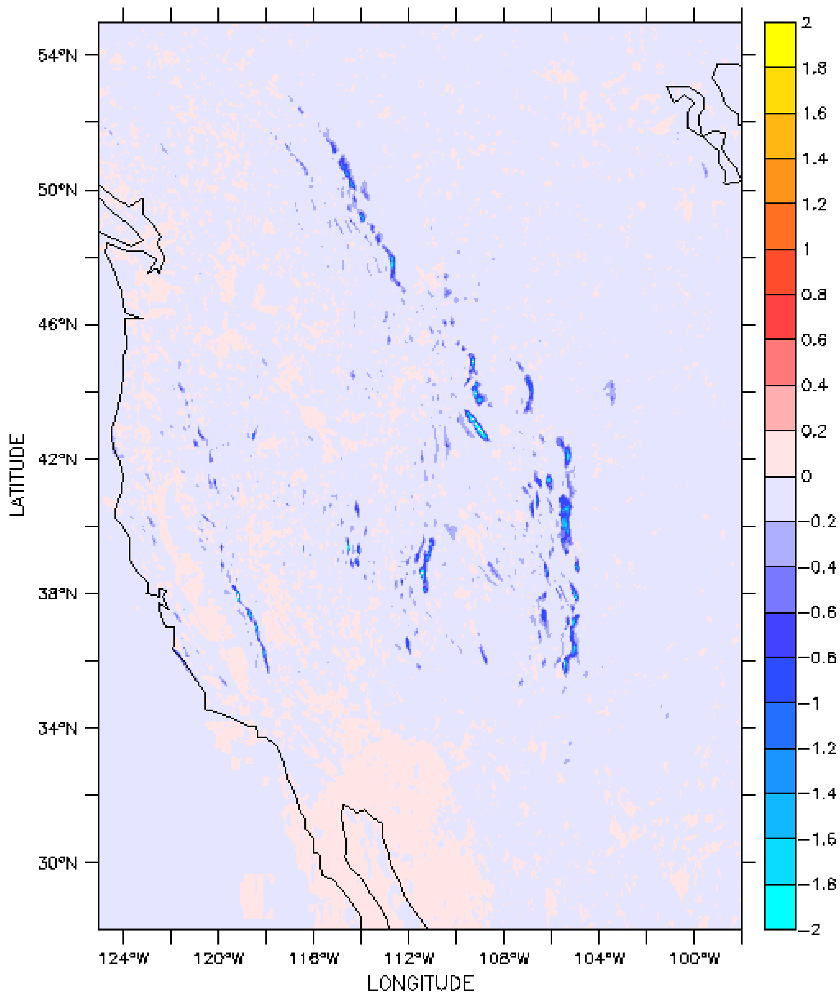
we can find the drag coefficients a and b that give the best fit to the total base flux in the high-resolution run:

$$\begin{pmatrix} |\boldsymbol{F}^{\uparrow}{}_{1}| \\ |\boldsymbol{F}^{\uparrow}{}_{2}| \\ \vdots \\ |\boldsymbol{F}^{\uparrow}{}_{n}| \end{pmatrix} = \begin{pmatrix} |\boldsymbol{F}^{\uparrow}{}_{lin,1}| & |\boldsymbol{F}^{\uparrow}{}_{nl,1}| \\ |\boldsymbol{F}^{\uparrow}{}_{lin,2}| & |\boldsymbol{F}^{\uparrow}{}_{nl,2}| \\ \vdots & \vdots \\ |\boldsymbol{F}^{\uparrow}{}_{lin,n}| & |\boldsymbol{F}^{\uparrow}{}_{nl,n}| \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix}$$

Best Fit: $a = 1.2 \pm 0.4$, $b = 2.6 \pm 0.4$

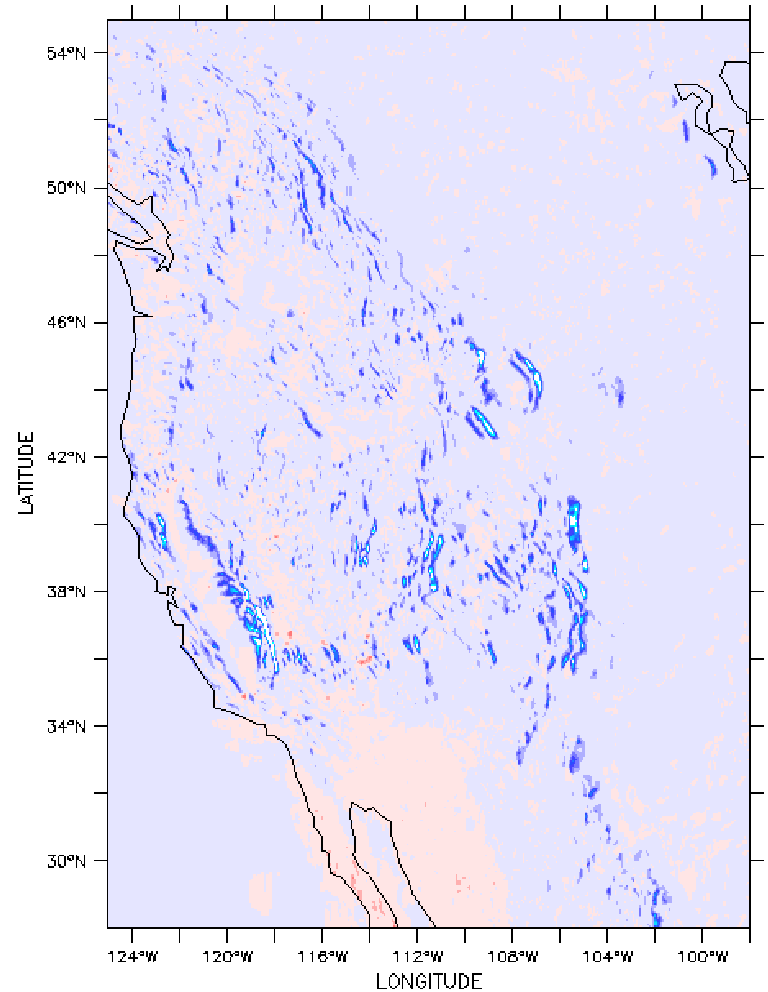
Components of base flux

Linear



zonal baseflux (propagating, N/m^2)

Nonlinear

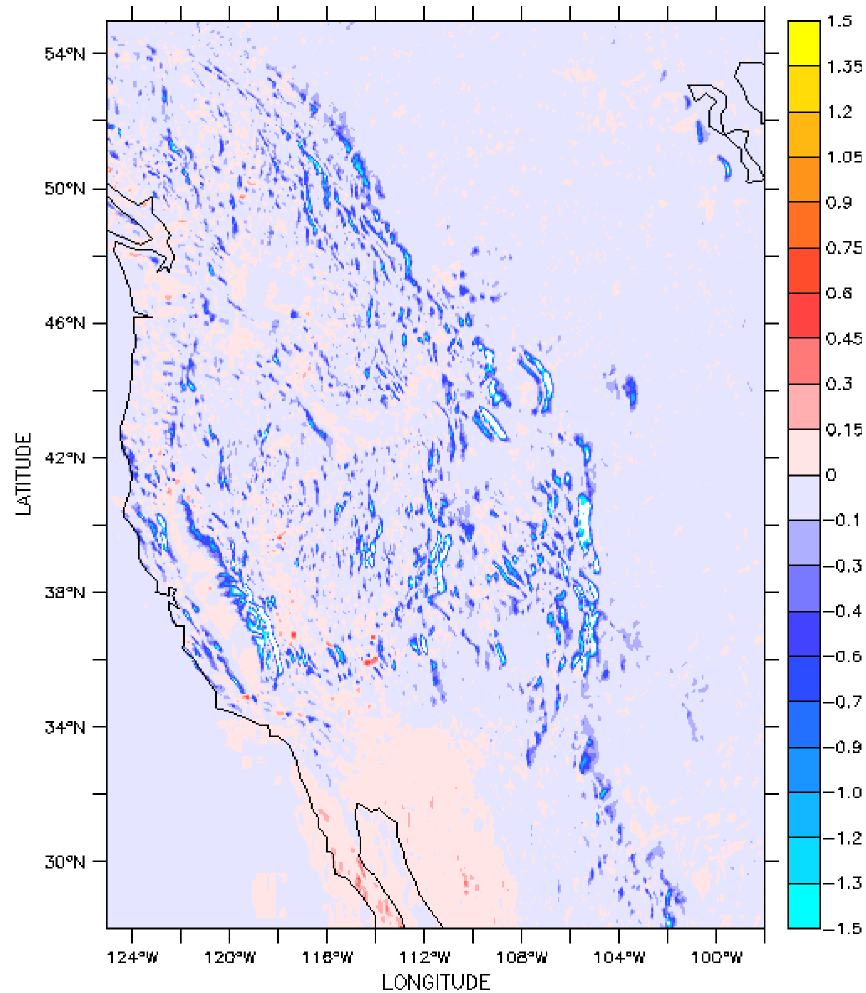


zonal baseflux (non−prop, N/m^2)

Garner, *JAS*, 2005

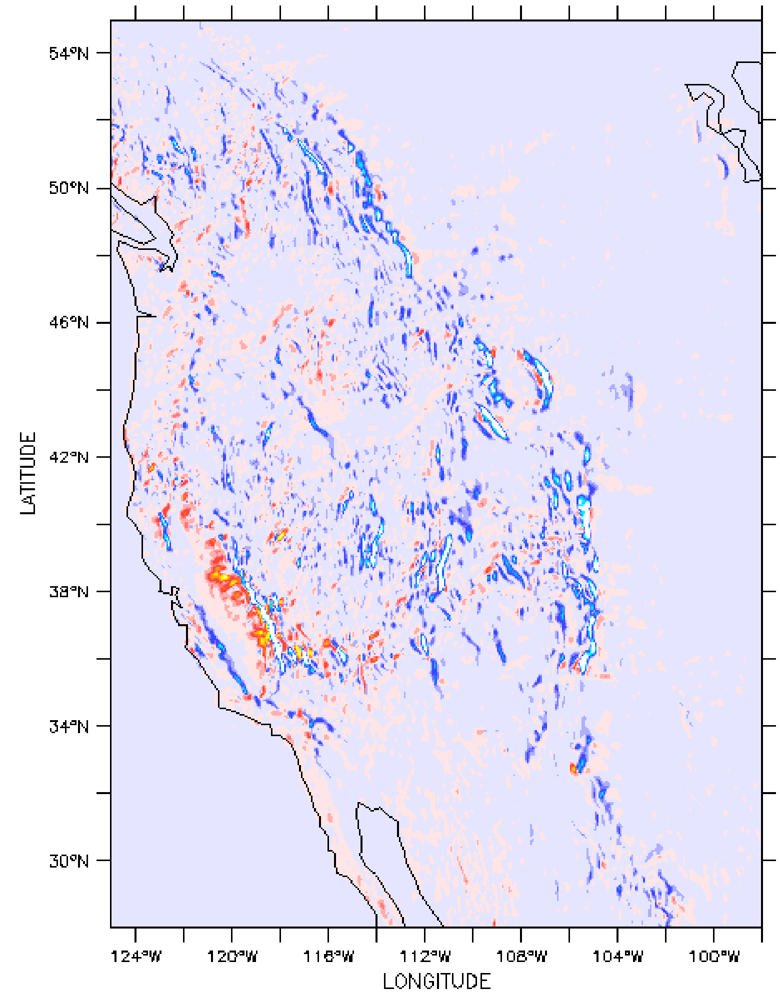
Base flux comparison

Parameterized



zonal baseflux (N/m~2)

Simulated



zonal baseflux (N/m~2)

Linear base-flux parameterization

The linear drag (with angle brackets denoting the grid-cell average) is

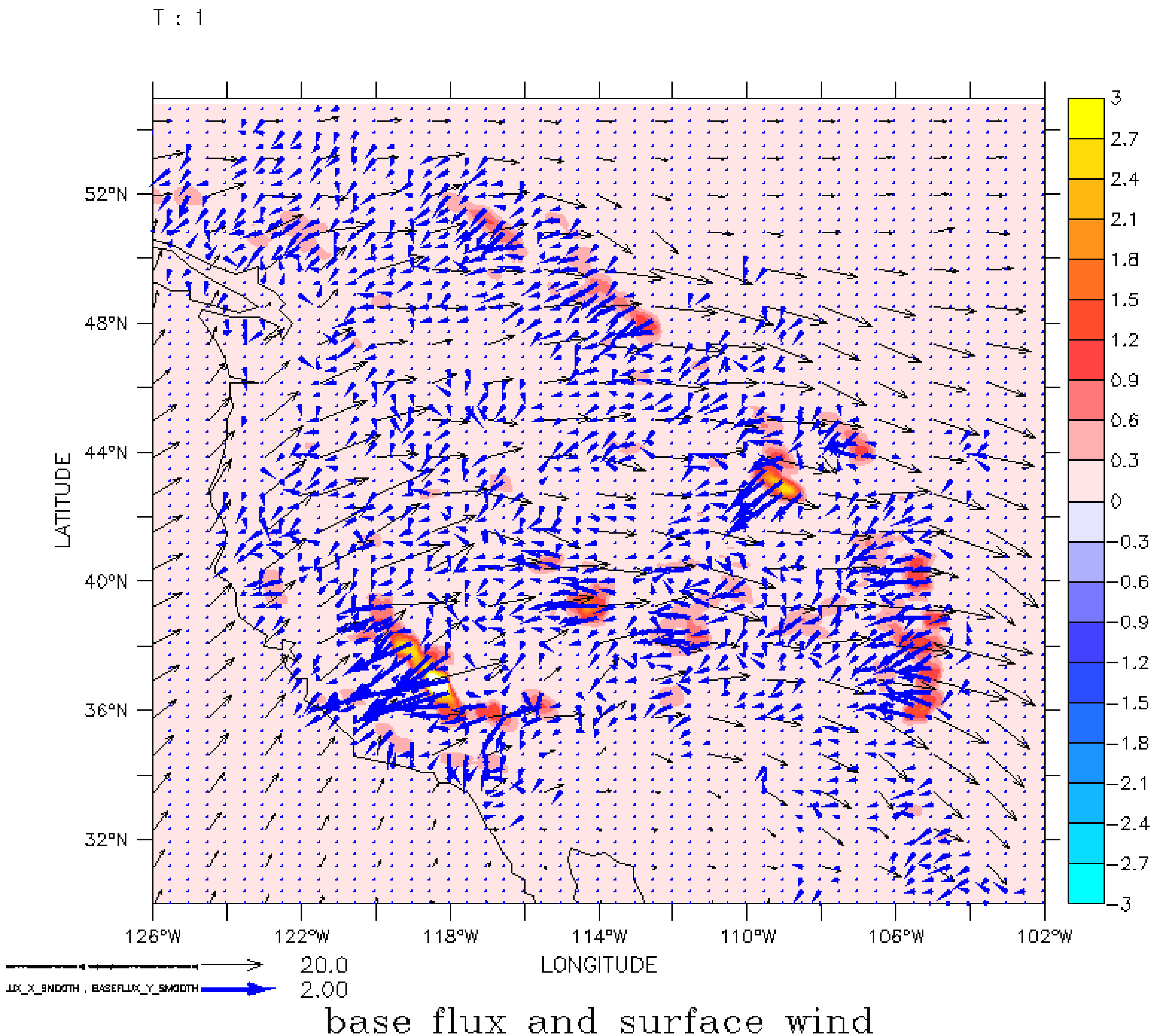
$$\vec{\boldsymbol{\tau}} = \bar{\rho}\langle \vec{\boldsymbol{V}}' w' \rangle = \bar{\rho} \begin{pmatrix} \left\langle u' \frac{\partial h}{\partial x} \right\rangle & \left\langle u' \frac{\partial h}{\partial y} \right\rangle \\ \left\langle v' \frac{\partial h}{\partial x} \right\rangle & \left\langle v' \frac{\partial h}{\partial y} \right\rangle \end{pmatrix} \begin{pmatrix} \bar{u} \\ \bar{v} \end{pmatrix}$$

For $\vec{\boldsymbol{V}}'$, we assume steady, non-rotating and hydrostatic internal waves.
If $\vec{\boldsymbol{V}}' = \vec{\boldsymbol{\nabla}}\chi$, linear theory gives

$$\chi = (\bar{N}/2\pi) \iint \frac{h(\vec{\boldsymbol{x}}')}{|\vec{\boldsymbol{x}} - \vec{\boldsymbol{x}}'|} dx'dy'$$

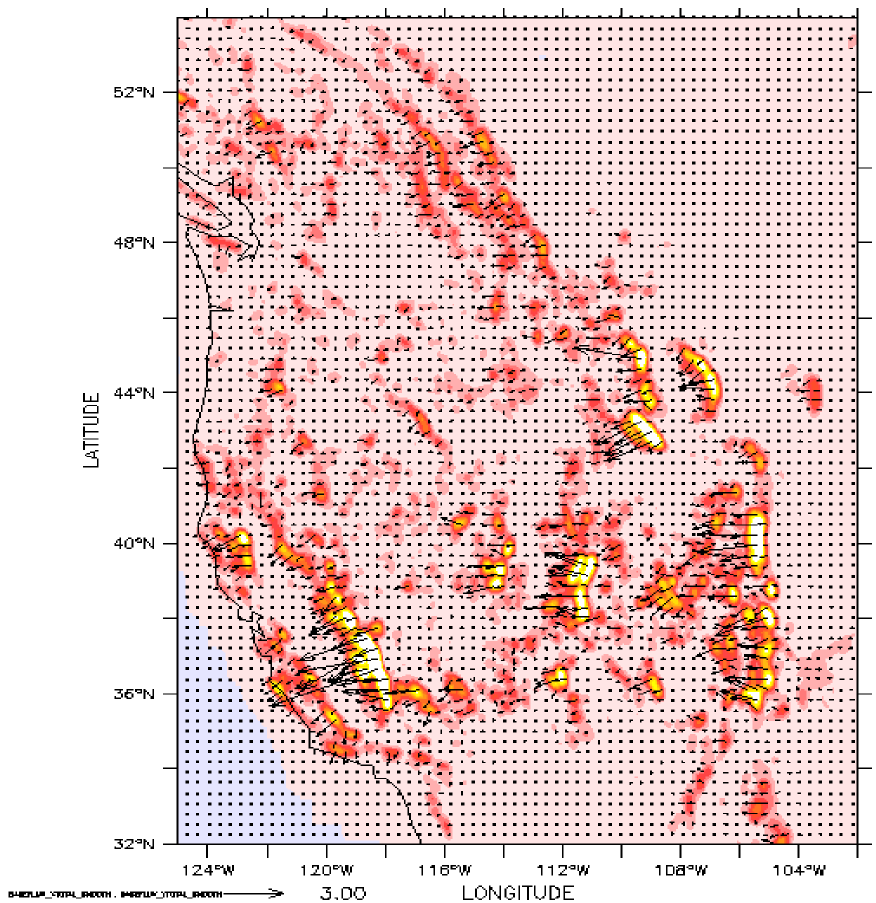
The averaging of the 4 matrix elements can be done offline. The topography *h(x,y)* has to be filtered for both physical and computational reasons.

Surface wind and parameterized base flux



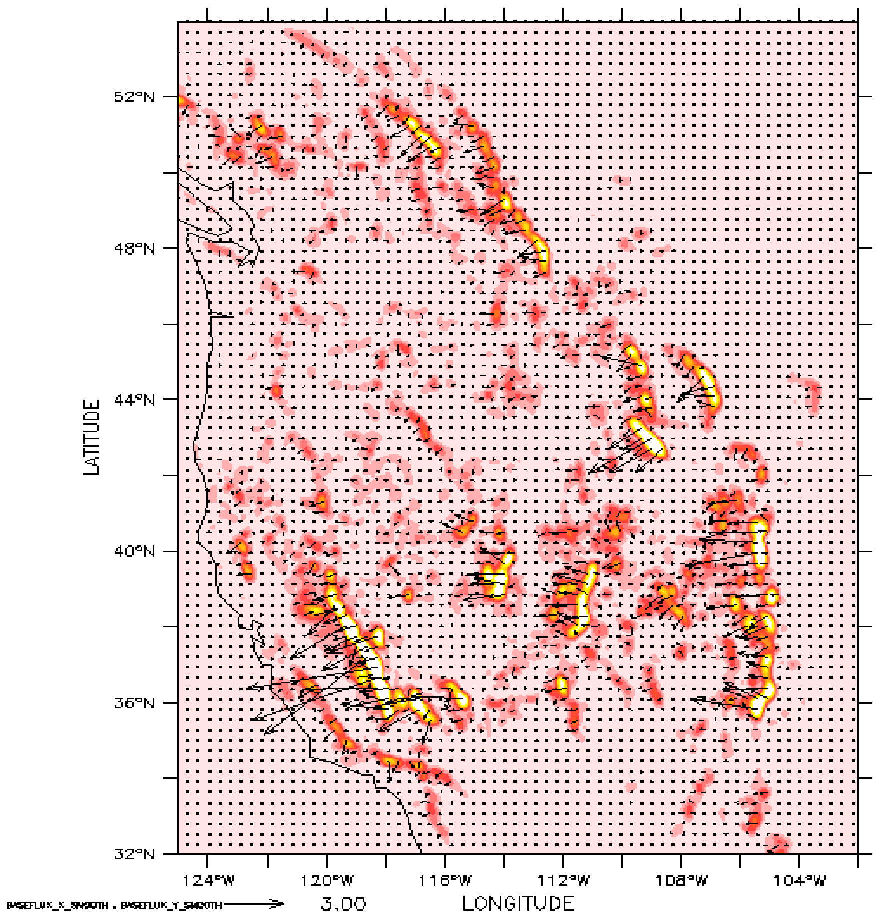
Total base flux

Parameterized



base flux (N/m^2)

Simulated

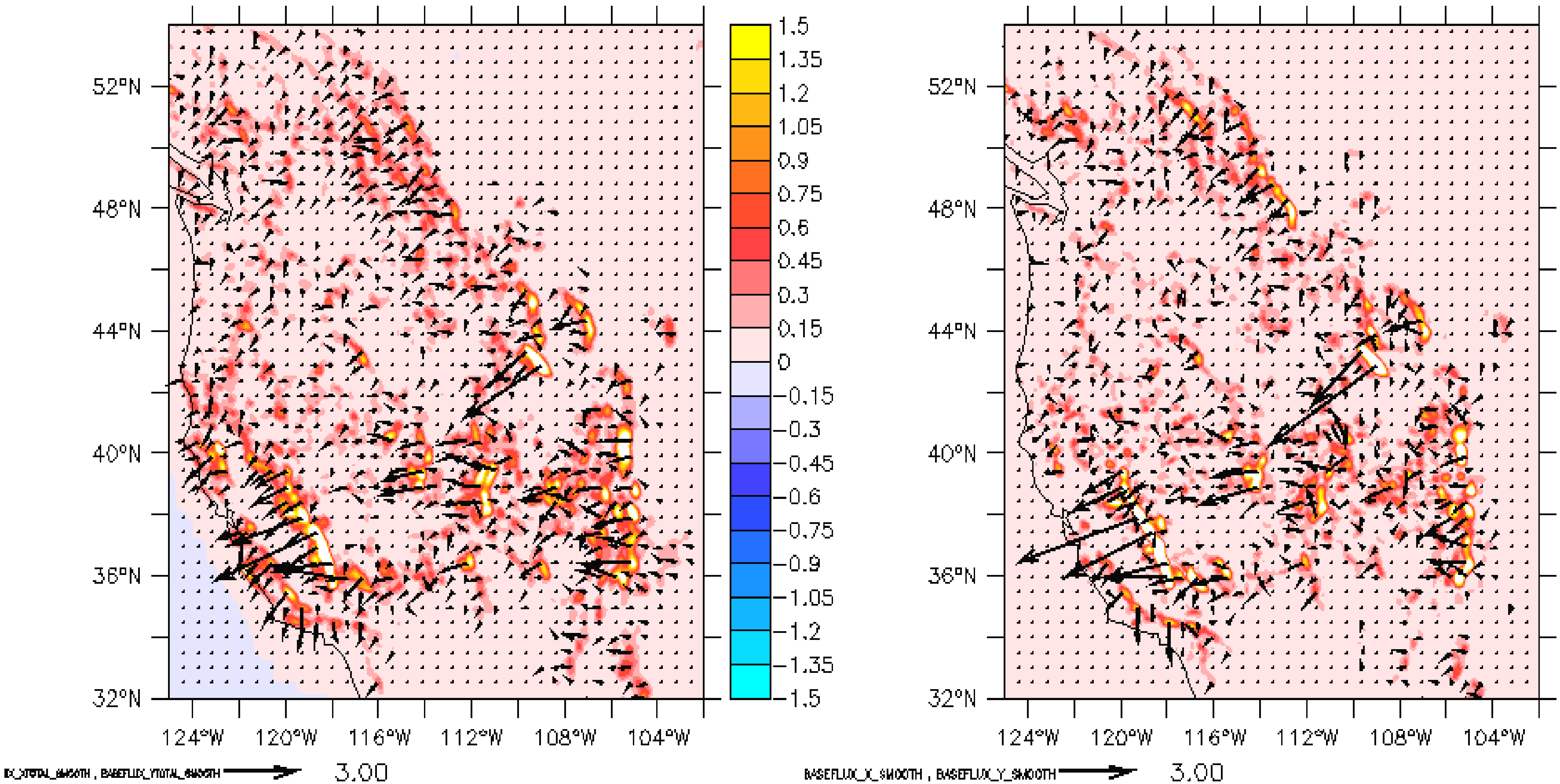


base flux (N/m^2)

Base-flux vectors
idealized jet

Parameterized

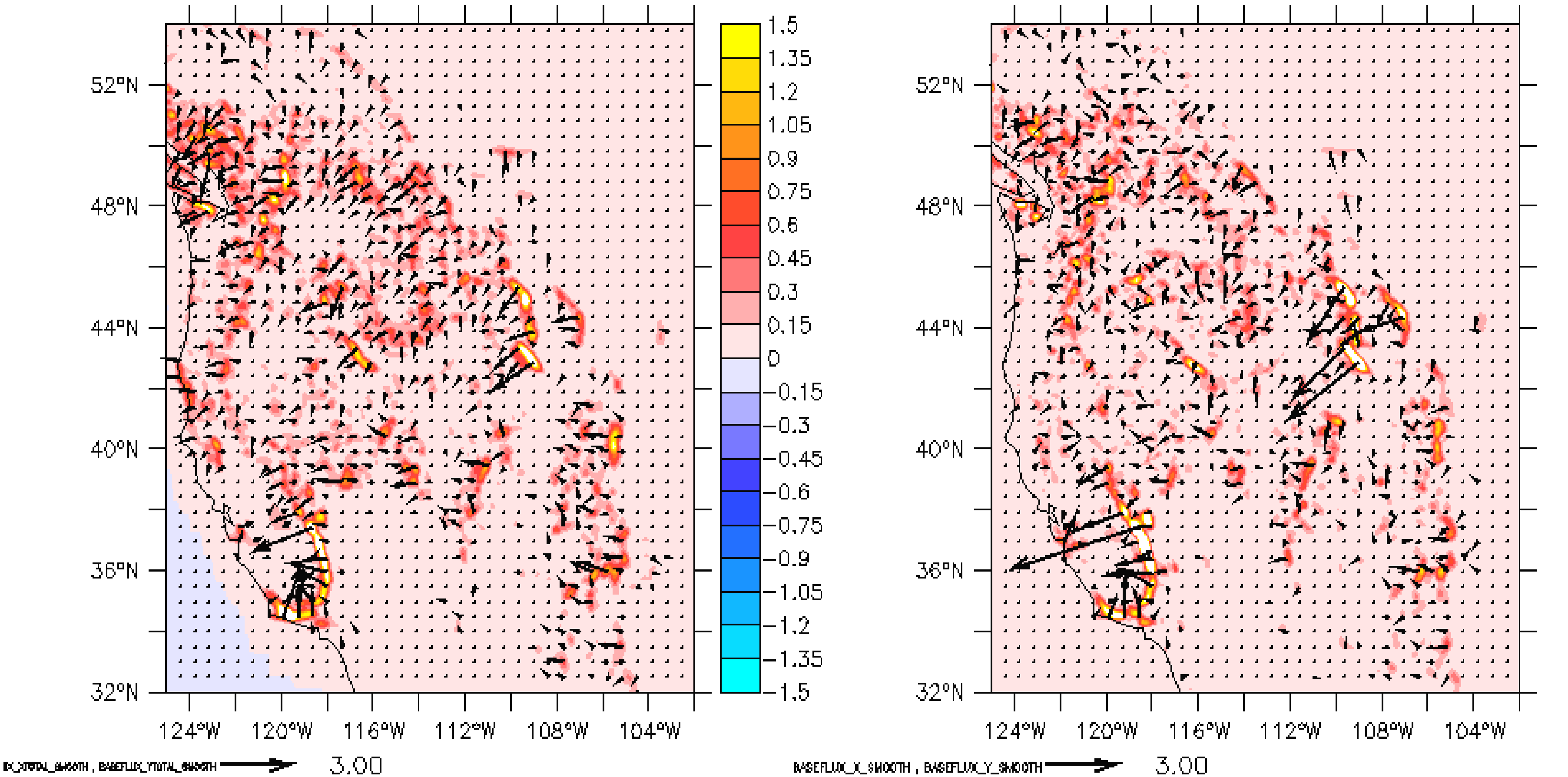
Simulated



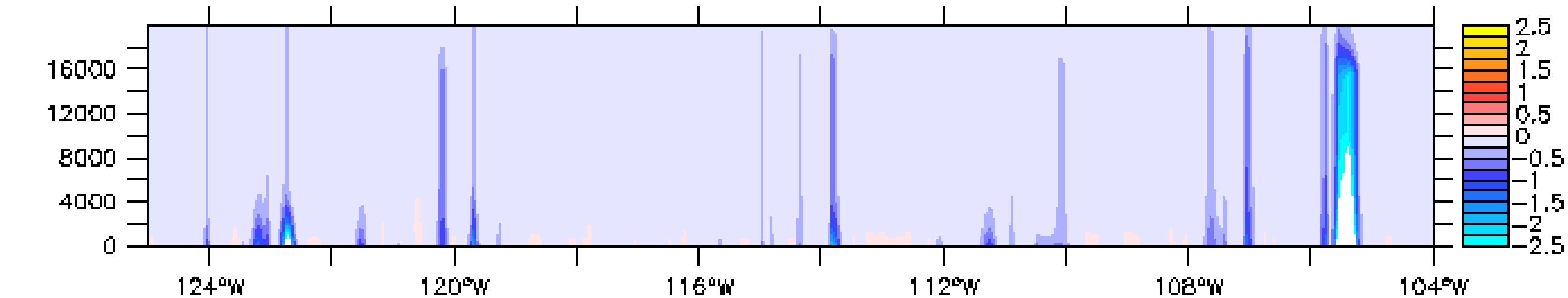
Base-flux vectors
January reanalysis

Parameterized

Simulated

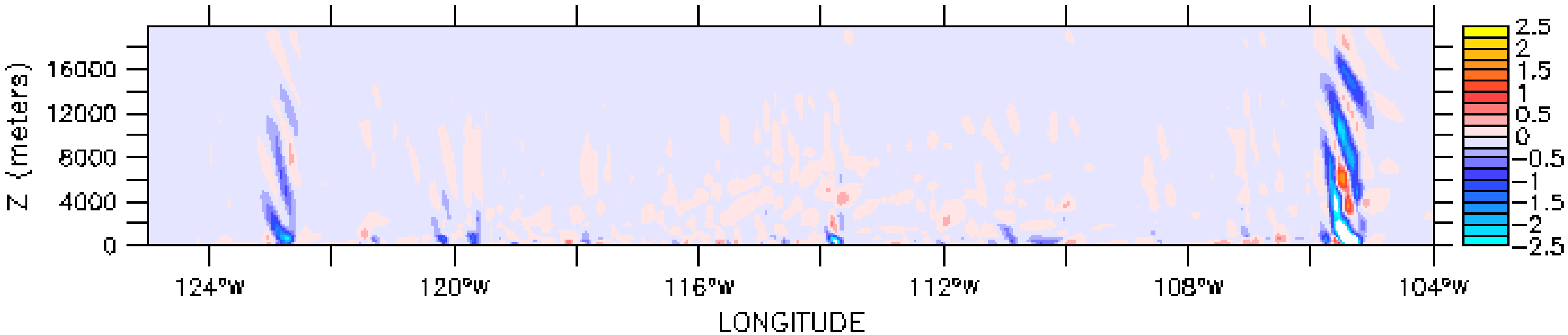


parameterized



Section at 40°N

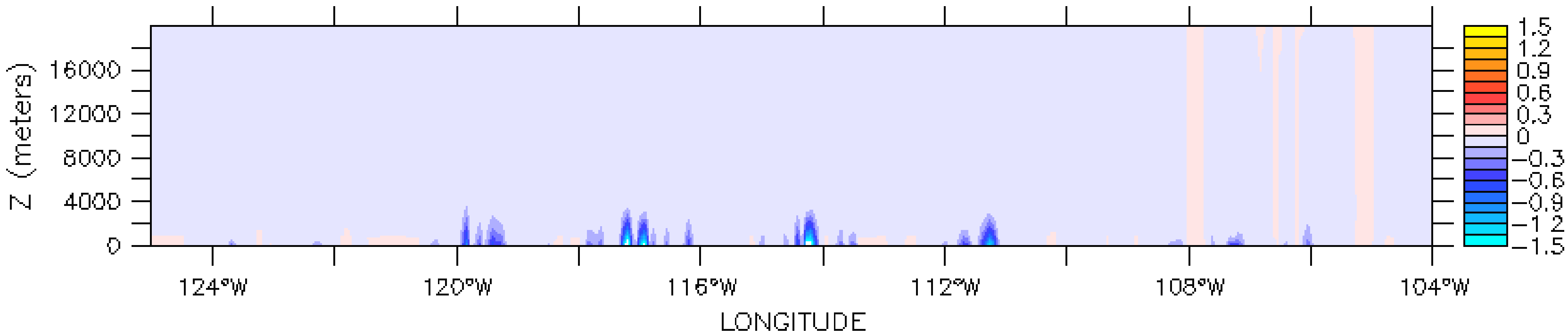
simulated



zonal flux (N/m~2)

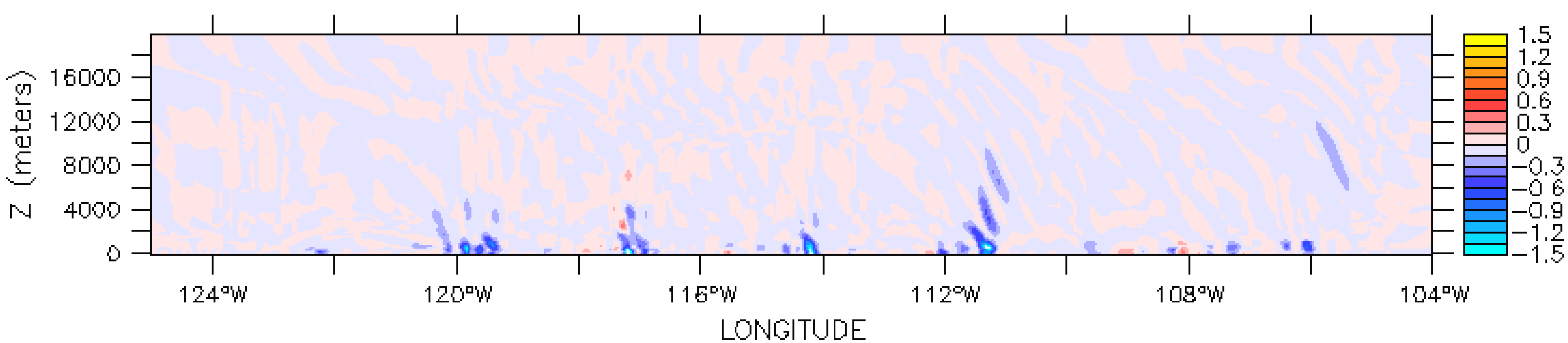
LATITUDE : 39N

parameterized



zonal flux (N/m~2)

simulated



zonal flux (N/m~2)

To conclude:

- A drag-resolving model is costly, but short integrations suffice
- The local momentum flux can be diagnosed with a divergence filter
- Friction allows a significant divergence of the flux through the PBL
- The simulated local flux successfully “tunes” the drag coefficients
- The direction of the drag is not much altered by nonlinearity
- Wave penetration (although w/o explicit breaking) matches fairly well

Thank you.